

Mobile logistics hubs prepositioning for emergency preparedness and response in Nepal

Mobile
logistics hubs
prepositioning

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Abstract

Purpose – The purpose of this study is to develop a methodology which amalgamates quantitative and qualitative approaches to determine the best placement of mobile logistics hubs (MLH) to be established in different parts of Nepal as a part of real-life project, “Augmentation of National and Local-Level Emergency Logistics Preparedness in Nepal” (2017–2020), implemented by the World Food Programme in cooperation with the Government of Nepal.

Design/methodology/approach – The study develops a methodology using a combination of a modified version of the maximal covering location problem (MCLP) and focus group discussion. The MCLP model is used to determine the optimal number and spatial location of MLHs, and focus group discussion is used to identify the five first-priority strategic MLH locations using expert knowledge.

Findings – The authors identify the five first-priority locations for establishing MLHs using an amalgamation of quantitative approach (mathematical model) and qualitative approach (focus group discussion). By amalgamating mathematical model with expert knowledge, findings acceptable to a wide range of stakeholders are obtained. The focus group discussion helps to pinpoint the location of MLHs to city-level granularity which is otherwise impossible with data available on hand.

Research limitations/implications – Although multiple experts’ judgements were obtained via focus group discussion, subjectivity and possible bias is inevitable. Overall, the quantitative results of the study are purely based on the data available during the study period; therefore, having updated data could possibly improve the quality of the results.

Originality/value – This study is the first of its kind that uses an amalgamation of mathematical model and expert knowledge to determine the strategic locations of MLHs and has been successful to an extent that the selected locations have been vetted by the government of Nepal for establishing MLHs and are undergoing implementation in real life. This study also considers multiple disaster scenarios and employs the concepts of human development, disaster risk and transportation accessibility to reflect Nepal’s socioeconomic, geoclimatic and topographical features.

Keywords Humanitarian logistics, Integer programming, Maximal covering location problem, Emergency preparedness, Mobile logistics hub, Focus group discussion, Nepal

Paper type Research paper

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This study was conducted as a part of the project “Augmentation of National and Local-Level Emergency Logistics Preparedness in Nepal” (2017–2020) implemented by the World Food Programme in cooperation with the Government of Nepal.



1. Introduction

Disaster response can be extraordinarily challenging in developing countries (IFRC, 2004; Maharjan and Hanaoka, 2018) due to insufficient resources in the immediate aftermath, poor governance, weak infrastructure, damages to infrastructure and a general lack of information, including a response plan and the lack of knowledge of the socioeconomic circumstances in affected areas as evidenced by disasters like Nepal earthquake 2015 and Ecuador earthquake 2016. Hence, being prepared for disasters is critical to the success of humanitarian response efforts (Banerjee and Gillespie, 1994; Logistics Cluster, 2020). Unlike slow-onset disasters, sudden-onset disasters give responders a very short time to react and prevent further damage. Considering the urgency, uncertainty and complexity associated with managing disasters, enhancements in logistics and supply chain management directly affect the ability of humanitarian organizations to respond and improve the overall effectiveness of the response (Erbeyoğlu and Bilge, 2019). In this study, we present the case of mobile logistics hubs (MLH) prepositioning for emergency preparedness and response in Nepal.

Nepal is a landlocked developing country in South Asia in the central Himalaya mountain range. The country is prone to various types of natural disasters due to its rugged, fragile and diverse geophysical structure, which is characterized by very high peaks, complex geology, active tectonic processes, unplanned settlements, variable climatic conditions and weak economic and political circumstances (ADPC, 2010). Every year, numerous floods, landslides, fires, epidemics, avalanches and other natural and human-made crises cause loss of hundreds of lives and billions of USD worth of property. Amid the different types of disasters that threaten Nepal, earthquake, landslide and flood are the three most common types of sudden-onset disasters that have claimed the highest number of lives and people affected (a total of 28,040 deaths and 12.4 million lives affected from the year 1900 till 2019) (CREED, 2016).

Nepal's high-risk profile due to its vulnerability to various natural disasters provides a compelling case for research and investment in emergency preparedness. Also, the country's lack of large-scale warehousing facilities for the humanitarian community and a severely underdeveloped infrastructure pose enormous challenges as well as risks during any emergency relief operations in Nepal. A Humanitarian Staging Area that was established only a month before the April 2015 earthquakes quickly became an exemplar for emergency coordination and response not only within Nepal but worldwide (Wendelbo *et al.*, 2016). However, the humanitarian response operations during the 2015 earthquakes exposed several gaps in the nation's logistics infrastructure that caused a slowdown in the emergency operations. Some of the crucial findings cited by the Logistics Cluster report highlighted the congestions at the country's only international airport, Tribhuvan International Airport, caused as a result of a flight size limitation of 190 metric tons, physical access constraints due to poor access, lack of logistics infrastructure and increased risk of post-earthquake landslides (Logistics Cluster, 2016).

In accordance with the priorities for action outlined by the Sendai Framework for Disaster Risk Reduction 2015–2030, the National Disaster Risk Reduction Strategic Action Plan 2018–2030 and the United Nations Development Assistance Framework 2018–2022 for Nepal have emphasized on the need for a more holistic/ multi-hazard understanding of disasters along with the need to invest into infrastructure development for increasing disaster risk reduction capabilities and resilience. A brief look at Nepal's budget revealed almost no funds allocated for disaster preparedness activities, except for awareness training up to the year 2014 (MoF, 2014). A small portion of the budget was allocated for reconstruction and recovery after the April 2015 Nepal earthquake (MoF, 2015). Given the current situation, Nepal is severely underprepared for future disasters.

To enhance the primitive nature of disaster preparedness and safeguard the population at risk, this study aims to determine the location of MLHs to be placed in different parts of Nepal with the aim of increasing the efficiency and effectiveness of emergency response operations. An MLH is defined as a place pre-designated for storing emergency logistics and emergency telecommunication equipment. The main aim of establishing an MLH is to preposition logistics equipment such as Mobile Storage Units (MSUs) required to establish a relief logistics operation center near the disaster-affected areas. This will enable the quick establishment of an operation center that can function as a humanitarian platform for the management of disaster relief items with the availability of necessary communication systems. MLHs are to be strategically located in different parts of Nepal with the ability to cover districts vulnerable to sudden-onset disasters floods, landslides and earthquakes.

Although research on facility location problem is abundant in the domain of humanitarian operations, from a methodological point of view, facility location models have typically been dealt by using either quantitative measures or qualitative measures, where an amalgamation of the two methods is generally lacking (Maharjan and Hanaoka, 2019). Especially in developing countries, valuable data and information which often remains in the form of expert knowledge is hard to capture using quantitative measures alone, and hence remains unexplored. Therefore, combining quantitative and qualitative measures is the key to generating results that can be implemented in real life and assist in decision-making. Moreover, investigations that focus on location problems and simultaneously consider multiple disaster vulnerabilities, the availability of basic data, factors unique to the country/region being examined which contain reflections on the current state of disaster preparedness in the country and dynamics involved in humanitarian decision-making are deficient in the literature. From an implementation point of view, it is uncommon to come across academic studies whose results are implemented in real life.

To address these gaps in the literature and practice and to support strategic decision-making, we develop a methodology that includes an optimization model and a focus group discussion to enable selection of MLH locations that are optimal from a mathematical point of view and strategic from practitioner's point of view and illustrate the importance of incorporating qualitative approach when conducting scientific studies to enhance applicability in real life. The results of this study have been vetted by the Government of Nepal and are in process of implementation in different parts of Nepal.

The paper is structured as follows: Section 2 discusses relevant facility location models used in humanitarian operations. In Section 3, we present the methodology implemented in the study. Section 4 presents and discusses the results obtained. Finally, Section 5 concludes the research and suggests further research opportunities.

2. The literature on facility location models in humanitarian operations

One of the most important aspects of humanitarian operations is to decide where to locate facilities such as MLHs. While there are many variants to modeling location problems, Boonmee *et al.* (2017) classified location models based on the data modeling types and problem types: deterministic facility location problems, stochastic facility problems, dynamic facility problems and robust facility problems. The deterministic location models can be further classified into the minisum facility location problem, the covering problem and the minimax facility location problem. In this study, we model our problem as a covering problem under the category of pure location model. Covering models are one of the most widely used location models for formulating emergency facility location problems (Jia *et al.*, 2007). Interested readers can refer to Boonmee *et al.* (2017) for a detailed

review of facility location models in humanitarian operations, and Farahani *et al.* (2012) and Berman *et al.* (2010) for covering problems in facility location in non-humanitarian operations.

A covering problem can be further categorized as a maximal covering location problem (MCLP) or a set covering location problem (SCLP). *Coverage*, a notion that is central to facility location models, indicates whether a demand location is within a pre-specified radius (measured by distance, travel time, cost or another metric) of the nearest facility. The source of demand is considered “covered” if it is located within a specified response radius from a facility. The SCLP, first introduced by Hakimi (1965), seeks to minimize the number of facilities among a finite set of candidate sites such that all demand sources are covered. In disaster relief, this would mean that a potential demand point must be within a specified target response time of a facility in the relief network. On the contrary, the MCLP maximizes the total demand covered within a maximal service distance, which is subjected to a limited number of facilities or resource constraints. Therefore, a maximal covering-type model is more suitable for designing relief chain networks.

The P -median problem attempts to minimize the sum of the distances (i.e. average distances) between demand points and their nearest facilities. Although the MCLP and P -median problems address similar problem categories, P -median problem aims to minimize the total demand-weighted distance between each demand node and the nearest facility. Put simply, this means pinpointing the locations of P -facilities in a network such that the total distance is minimized. However, Lee and Yang (2009) concluded that the P -median problem approach does not optimize demand coverage or site locations, because in this approach, distance and time parameters can outweigh demand values, resulting in locations that are outliers. The MCLP approach avoids this by changing the objective from minimizing travel distance to serving the greatest possible number of people. Furthermore, coverage models are known to be best for “worst-case scenarios” (Tayal and Singh, 2019) because the goal is to ensure the best possible response, even for the most remote demands in the network.

Church and ReVelle first introduced the MCLP in 1974. Subsequent developments of it were led by Chung (1986), Megiddo *et al.* (1983) and Daskin *et al.* (1988). Many researchers such as Basdemir (2004), Jia *et al.* (2007), Balcik and Beamon (2008), Murali *et al.* (2012), Santos *et al.* (2013), Abounacer *et al.* (2014) and Chanta and Sangsawang (2012) have used the MCLP to choose locations. In the humanitarian context, Jia *et al.* (2007) focused on facility location for medical supplies using a case of epidemics; Balcik and Beamon (2008) consider facility location decision for a humanitarian relief chain responding to quick-onset disasters using worldwide disasters caused by earthquakes; Murali *et al.* (2012) consider facility location problem to determine the points in a large city where medicine should be handed out to the population using a hypothetical case of anthrax attack; Chanta and Sangsawang (2012) address shelter-site selection problem using floods to illustrate their cases; and Santos *et al.* (2013) consider flood facility location-allocation for evacuation planning using the case of flood. However, it is important to note that these studies are neither implemented in real life nor have considered qualitative aspects of location problem.

Although there are several types of objectives that can be chosen for modeling facility location problem, typically the objective of choice in humanitarian operations is to maximize demand satisfaction or minimize response time (e.g. Balcik and Beamon, 2008; Mete and Zabinsky, 2010; Salmeron and Apte, 2010; Duran *et al.*, 2011; Bozorgi-Amiri *et al.*, 2013; Bazinpour and Esmaeili, 2014; Rennemo *et al.*, 2014 and Jahre *et al.*, 2016) which aligns with the objective chosen in this study.

While there are several approaches to modeling a location problem, we have limited our literature review to studies using MCLP for facility location for real-life humanitarian operations and studies using an amalgamation of qualitative and quantitative approaches. Abundant existing literatures in the domain of humanitarian logistics studies have found that, typically, less than 15% of analytical papers on humanitarian logistics test the proposed formulations with real data, highlighting that there is a big disruption between these models and practice (Leiras *et al.*, 2014; Cotes and Cantillo, 2019). The number of studies with actual case studies using multiple disasters is rare to come across. Kunz and Reiner (2012) found underrepresentation of empirical research in a literature review of 174 papers. Kovacs *et al.* (2019) stated that, currently, mixed methods are not used and empirical evidence in publications is scant, thereby undermining both the rigor and the relevance of humanitarian logistics research. We aim to address these gaps in existing literature and contribute to the existing body of knowledge by developing a new methodology to enhance disaster preparedness and response.

3. Methodology

We developed a methodology which includes an optimization model and a focus group discussion to identify optimal and strategic locations of MLHs to be placed in different parts of Nepal. An amalgamation of these approaches plays an important role to enable the generation of optimal and strategic solutions. In developing countries, it is particularly difficult to obtain quantitative data, and data often exist in the form of knowledge gained by experts in due process. Therefore, methodology like the one presented here enables eliciting important knowledge and information that serves to generate solutions that are acceptable to a wide range of stakeholders and can be implemented in real life. The methodology has been developed to align with the overarching goal of establishing a sustainable and flexible “logistics backbone” that can respond to the multiple disaster scenarios which face Nepal, by establishing five MLHs in different parts of Nepal. The methodology developed in this study operates in two sequential steps. In the first step, we identify the optimal number and spatial location of MLHs. In the second step, we identify the strategic locations of the MLHs. The details of each step are explained in the subsequent sections.

3.1 Determining the number and spatial location of mobile logistics hubs

We formulate a modified version of MCLP to determine the number and spatial location of the MLHs. The original formulation of MCLP maximizes the total demand covered within a maximal service distance, which is subjected to a limited number of facilities or resource constraints. Generally, when designing a humanitarian supply chain network, it is important to make sure that the established facilities can cover the demand areas within stipulated coverage distance. Therefore, this study has implemented the notion of coverage. Figure 1 shows an illustration of the concept of coverage. In Figure 1, PoDs that are located within the D distance, termed as “coverage distance,” are considered “covered,” whereas points of distribution (PoDs) represented by hollow triangles that lie outside the D distance are considered “uncovered”.

The uncertainty of disaster occurrence is reflected using scenarios of floods, landslides and earthquakes to determine vulnerable demand nodes termed as PoDs in this study. Important factors such as the actual distance between the prospective MLH locations and PoDs, road accessibility and connectivity and sustainable operability of the MLHs in the selected locations are also included in the model. The model maximizes the coverage of PoDs subject to a set of three constraints: (1) the transportation accessibility constraint, (2) the development constraint and (3) the disaster safety constraint. These constraints are not

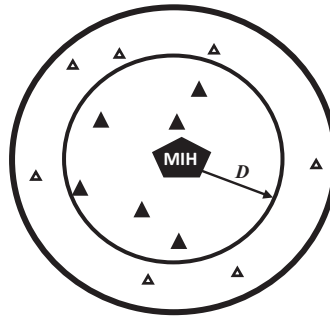


Figure 1.
Illustration of the
concept of coverage

Where,
 D stipulated coverage distance within which MLHs can cover PoDs
 \blacktriangle PoDs “covered” within the stipulated coverage distance
 \triangle PoDs “uncovered” within the stipulated coverage distance

included in the original formulation developed by Church and ReVelle (1974), and therefore are the contribution of this study. The model includes the candidate points, which are the potential sites for MLHs and the PoDs that need to be covered by MLHs. We consider all the districts with no existing warehouses nor planned by the Government of Nepal or national and international non-governmental organizations as the candidate MLH locations. Each MLH has a planned storage capacity of 1,000 metric tons.

3.1.1 Formulation of the MLH model. We have formulated our model with reference to the original formulation proposed by Church and ReVelle (1974), under additional constraints (4)–(6) to meet this study’s requirements. This aligns with the idea presented in our earlier paper Maharjan and Hanaoka (2017). The modified MCLP has been formulated as a static, single-stage deterministic problem based on the following assumptions:

- (1) The locations of MLHs are assumed to be in district headquarters.
- (2) All PoDs have road access to and from the candidate MLH locations.
- (3) The PoDs are either fully covered or uncovered. There is no provision for partial coverage; the coverage follows binary requirements.

The mathematical formulation is as follows:

$$\text{Maximize } \sum y_i \tag{1}$$

$$\text{S.T. } \sum x_{j \in S_i} \geq y_i \quad \forall i \in I \tag{2}$$

$$\sum x_j \leq P \tag{3}$$

$$\sum T_j x_j \geq N_T \sum x_j \quad \forall j \in J \tag{4}$$

$$\sum D_j x_j \geq N_D \sum x_j \quad \forall j \in J \tag{5}$$

$$\sum V_j x_j \leq N_V \sum x_j \quad \forall j \in J \tag{6}$$

$$x_j \in \{0, 1\} \quad \forall j \in J \tag{7}$$

$$y_i \in \{0, 1\} \quad \forall i \in I \tag{8}$$

Where,

I = denotes the set of PODs;

J = denotes the set of MLHs;

D = coverage distance; the distance beyond which a PoDs is considered uncovered;

P = number of MLHs to be located;

d_{ij} = the shortest distance from node i to node j ;

$$x_j = \begin{cases} 1 & \text{if an MLH is located at candidate site } j \in J \\ 0 & \text{if otherwise;} \end{cases}$$

$S_i = \{j \in J | d_{ij} \leq D\}$;

$$y_i = \begin{cases} 1 & \text{if a POD is covered within the coverage distance} \\ 0 & \text{if otherwise;} \end{cases}$$

N_T = the minimum threshold value for transportation accessibility;

N_D = the minimum threshold value for development index;

N_V = the maximum threshold value for disaster vulnerability index;

T_j = the transportation accessibility index value for candidate site j ;

D_j = the development index value for candidate site j ;

V_j = the disaster vulnerability index value for candidate site j .

The objective function (1) maximizes the total PoDs covered within the desired coverage distance. Equation (2) represents the coverage constraint. Equation (3) sets a limit on the total number of MLHs that can be opened to P . Constraints (4), (5) and (6) are the limiting constraints for transportation accessibility, level of development and disaster safety associated with candidate MLHs. These constraints help to establish minimum standards for choosing MLH locations. Equations (7) and (8) depict the nature of decision variables.

3.1.2 Identification of points of distribution. To identify the PoDs, we select three types of sudden-onset disasters (earthquakes, landslides and floods), with the premise that these three kinds of calamities combined result in the highest frequency of occurrence among all types of natural disasters in Nepal and have resulted in significant fatalities. It is worth noting that the three types are not mutually exclusive. The earthquake scenario is generated using the maximum number of fatalities projected in the study conducted by Robinson *et al.* (2018). The landslide scenario is generated based on the 2010 Nepal Hazard Risk Assessment report (ADPC, 2010). The flood scenario is generated using the flood risk measure presented by Dhonju *et al.* (2015).

Based on the generated scenarios, we develop a composite disaster vulnerability index (CDVI) using the arithmetic mean of the normalized values of earthquake, landslide and flood risks. Using a cut-off CDVI at 0.2 based on the mutual consensus of the study team, we identify the number and location of the vulnerable districts, which are then charted over the map of Nepal using Arc GIS 10.2.2.

3.1.3 Identification of point of distribution to be covered by mobile logistics hubs. Under the implementation strategy devised by World Food Programme, for the augmentation of national and local-level emergency logistics preparedness in Nepal, eight forward logistics bases (FLB) are planned/proposed to be established in Banke, Kailali, Kaski, Kathmandu, Morang, Parsa, Rupandehi and Surkhet districts. An FLB is the main staging area that forwards cargo to MLHs in the affected areas. Each FLB has planned storage capacity of 2,000 metric tons, with size dimension of 60×100 m. However, the coverage provided by the

planned/proposed FLBs is yet to be determined. Therefore, to avoid redundancy in demand coverage and ensure equitable reachability of different logistical facilities, we first determine the PoDs which can be covered by planned/proposed FLBs within the stipulated coverage distance. By removing the PoDs covered by FLBs, we obtain the PoDs to be covered by MLHs.

To identify the PoDs covered by FLBs, we propose to implement the original formulation of MCLP without the additional constraints. The mathematical formulation is as follows:

$$\text{Maximize } \sum y_i \tag{9}$$

$$\text{S.T. } \sum x_{j \in S_i} \geq y_i \quad \forall i \in I \tag{10}$$

$$\sum x_j \leq P \tag{11}$$

$$x_j \in \{0, 1\} \quad \forall j \in J \tag{12}$$

$$y_i \in \{0, 1\} \quad \forall i \in I \tag{13}$$

Where,

I = the set of PoDs

J = the set of FLBs

D = coverage distance; the distance beyond which a PoDs is considered uncovered;

P = number of FLBs to be located

d_{ij} = the shortest distance from node i to node j

$y_i = \begin{cases} 1 & \text{if PoDs } i \text{ is covered by FLB } j \text{ within the coverage distance} \\ 0 & \text{if not} \end{cases}$

$S_i = \{j \in J | d_{ij} \leq D\}$

$x_j = \begin{cases} 1 & \text{if FLB } j \text{ is selected} \\ 0 & \text{if otherwise} \end{cases}$

The objective function (9) maximizes total PoDs covered by FLBs. Constraint (10) represents the coverage constraint. Constraint (11) shows the maximum number of FLBs that can be sited. We consider the transport of relief items via roads, such that the distances between the FLBs and PoDs are the actual distances on Nepal's existing road networks. Constraints (12) and (13) depict the nature of decision variables.

3.1.4 Selection of constraints. We use the notion of transportation accessibility, level of development and disaster vulnerability as constraints to formulate the model. These three indices exemplify this study. The main idea behind using these constraints is to ensure that the determined MLH locations can meet the incoming demand within a short response distance, while also guaranteeing the safety and sustainability of the chosen location. This, in turn, ensures the safety of the emergency relief items stored in the MLHs. Next, we explain the details of constraint selection.

The notion of transportation accessibility represents the accessibility constraint and is a proxy used to signify the ease of access to PoDs from the sites where MLHs might be placed. We derived the index values from road density data (DOLIDAR, 2016), which show kilometers of existing roads (per 100 square kilometers of land) for each PoDs. The notion of disaster vulnerability represents the vulnerability constraint and is a proxy used to reflect each PoDs's safety level. Here, the term *safety* means that districts are less vulnerable to disasters and are thus safer locations for placing MLHs. Each district is susceptible to

different types of disasters and therefore exposed to varying degrees of risk; thus, each district has a unique value in the vulnerability index. The candidate MLHs are assigned CDVI. The notion of the level of development represents the development constraint and is a proxy used to illustrate and compare each candidate MLH's level of development. We derived the data for this index from the human development index (NPC, 2014), which is essentially a measure of life expectancy, education and per capita income indicators.

We determined internodal distance by using a combination of a web-based application called the shortest distance calculator provided by Nepal's Department of Roads (Department of Roads, 2019) and a strategic road network GIS file. This calculator is unique to Nepal; it has an updated database of road networks within the country.

3.2 Focus group discussion

To share the results of the study, reach a consensus on the strategic locations of MLHs and identify the priority of the establishment of MLHs for the actual implementation of the study results, we propose a focus group discussion to be held on a national level. A focus group discussion involves gathering people from similar backgrounds or experiences together to discuss a specific topic of interest. It is a form of qualitative research which aims to obtain data from a purposely selected group of individuals rather than from a statistically representative sample of a broader population (Nyumba *et al.*, 2018). Focus group discussion, in contrast to MCDM, does not use predefined criteria; instead, it uses the knowledge and experience of purposely selected group of individuals to identify suitability and priority of MLH locations. The strength of focus group discussion relies on allowing the participants to agree or disagree with each other so that it provides an insight into how a group thinks about the MLH location alternatives based on their experiences and practices enabling generation of acceptable solutions (ODI, 2009). The details on how to conduct focus group discussions are presented and discoursed below.

3.2.1 Population sample selection. A population sample is chosen for the focus group discussion based on convenience sampling. However, individual participants from various stakeholder organizations are to be identified as potential participants based on their several years of prior experience in the humanitarian logistics sector, policy-making and their 10+ years of work experience in the humanitarian landscape of the country.

3.2.2 Group formation, structure and composition. Nepal is administratively divided into seven provinces. To select MLHs to be placed in different parts of Nepal, participants are divided into groups, where each group is assigned different province while also giving participants the freedom to join any of the groups based on their personal preference, area of expertise and past working experience in any of the province/geographical regions.

3.2.3 Execution of focus group discussion. A presentation seminar is organized to share the background, study consideration, methodology and the findings of the study. Participants are pre-informed about the results of the mathematical model. Each group is provided with (1) the materials necessary for discussion (details of the materials made available can be made available upon request), (2) three open-ended questions to discuss and (3) 60 min for discussion and 5 min for result presentation. Several facilitators are provided to facilitate the focus group discussion. The three open-ended questions were:

- (1) Does the group agree with the study's results and the priority to establish the MLHs? In case of a different order of priorities, clarify why?
- (2) Are there any MLHs that are not required? If yes, which ones and why?
- (3) For any of the MLH locations proposed, does the group recommend a different/better location? Clarify which MLH location (s) should be changed and why?

4. Results and discussion

We implemented the methodology developed above to identify optimal and strategic locations of MLHs to be placed in different parts of Nepal. The methodology has been implemented by using the latest data and statistics of Nepal under the newest administrative division. Focus group discussion was conducted by involving humanitarian experts with more than 10 years of experience in the humanitarian landscape of Nepal. We also illustrate the significance of using an amalgamation of quantitative and qualitative methodology in the subsequent sections.

4.1 Determining the number and location of mobile logistics hubs

Nepal’s seven provinces are administratively divided into 77 districts. The Government of Nepal along with other national and international non-governmental organizations has existing and planned warehouses of different forms and sizes in 18 districts located in Baitadi, Banke, Dang, Dhanusa, Doti, Kailali, Kanchanpur, Kaski, Kathmandu, Lamjung, Makwanpur, Morang, Panchthar, Parsa, Rupandehi, Sunsari, Surkhet and Udayapur districts of Nepal. Therefore, in this study, we consider the remaining 59 districts as candidate MLH locations.

4.1.1 Identification of points of distribution. Using a cut-off CDVI at 0.2, among a total of 77 districts, we pinpointed 70 disaster-prone districts which are identified as PoDs.

4.1.2 Identification of point of distributions to be covered by mobile logistics hubs. The result of the FLB model shows that a total of 37 districts can be covered by the established/proposed FLBs within the stipulated coverage distances of 100 and 150 km. Figure 2 shows the spatial location of FLBs and the PoDs covered by it over the map of Nepal. Results show that some districts like Bara, Bhaktapur, Banke, Kathmandu, Lalitpur, Makwanpur (to name a few) can be covered by more than one FLB. This is an important finding which allows the decision-maker to decide on multiple/different allocation strategies. Planned appropriately, multiple allocation strategies can help in building the resilience of the humanitarian supply chain. Another important observation is that FLBs in different locations have different numbers of

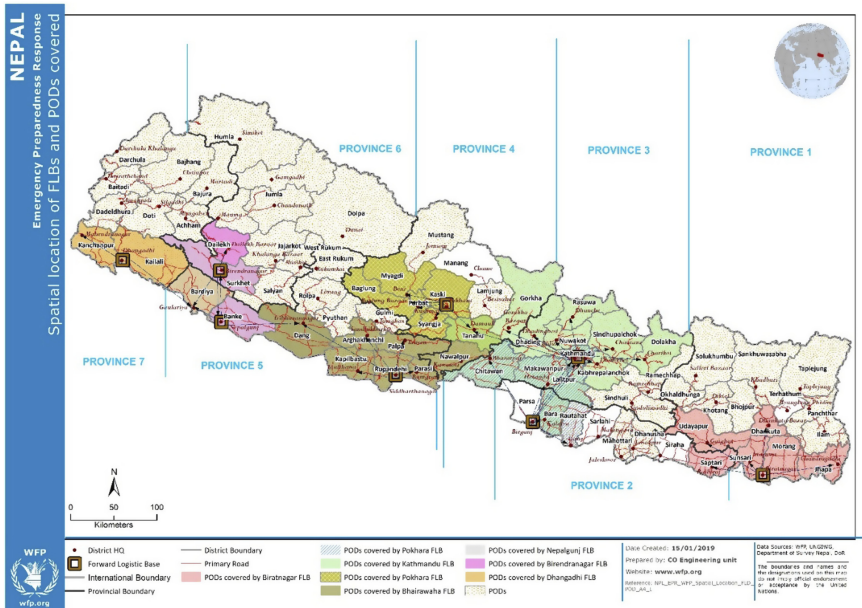


Figure 2. Spatial location of FLBs and PoDs covered

PoDs that they can cover. This provides insights for the planning capacities of the FLBs in future. Varying the capacities allocated to different FLBs based on their PoDs coverage can facilitate in minimizing establishment costs and inventory-related costs.

The remaining 33 PoDs located outside the coverage distance of the FLBs are therefore identified as the PoDs to be covered by MLHs.

4.1.3 Model implementation and results. The MLH model was implemented for a network of 33 PoDs and 59 candidate MLHs, with a coverage distance of 100 km. A coverage distance of 100 km is selected considering a maximum vehicular speed of 20 km/hr in the mountainous region and an average working hour of 8 h per day. The coverage distance selection is pertinent to a flatbed truck with a maximum loading capacity of 12 tons, the loading time of 1.5 h and an unloading time of 1.5 h. A threshold value of 30 km/100 sq. km land for road density, 0.37 for the level of development and 0.55 for disaster vulnerability are selected for the model implementation. We consider the transport of relief items via roads, such that the distances between candidate points and PoDs are the actual distances on Nepal’s existing road networks.

The model was coded using Lingo 18.0 optimization modeling software. All the experiments were run on a personal computer with an Intel (R) Core (TM) i5-7500 CPU (3.40 GHz) and 16 GB of RAM. Branch and bound algorithm was used for solving the optimization model. Model has 2040 total variables, 92 integer variables, 39 total constraints and 358 total solver iterations with a run time of 7 s for the optimal solution. All the other test problems including sensitivity analysis were computed in under 5 min.

Figure 3 shows the percentage of PoDs covered by a varying number of MLHs. We can observe 12 as the maximum number of MLHs which can be opened under given circumstances. An increase in the number of MLHs did not lead to an increase in coverage of PoDs. This could be because of two reasons: (1) although some of the candidate MLHs satisfy the coverage constraint, they do not have the desired level of transportation accessibility, level of development and CDVI; and (2) although some of the candidate MLHs satisfy transportation accessibility, level of development and disaster vulnerability constraints, they lie beyond the desired coverage distance.

The 12 MLHs are located in Achham, Bhojpur, Dadeldhura, Gulmi, Illam, Khotang, Mahottari, Okhaldhunga, Pyuthan, Ramechhap, Salyan and Tanahu, which can cover a total of 21 PoDs located in Accham, Bajura, Bhojpur, Baitadi, Dadeldhura, Doti, Gulmi, Illam, Panchthar, Khotang, Dhanusa, Mahottari, Sindhuli, Okhaldhunga, Solukhumbu, Pyuthan, Rolpa, Ramechhap, Rukum west, Salyan and Lamjung within a 100 km coverage distance. Table 1 shows the allocation of PoDs to MLHs. We can observe that a maximum of 3 PoDs

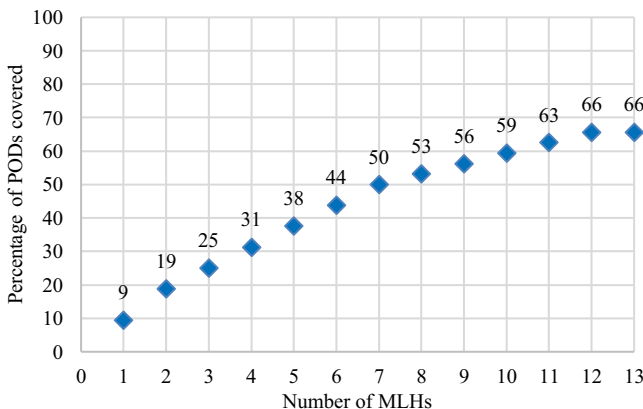


Figure 3. Percentage of PoDs covered by MLHs

Table 1.
Allocation of PoDs to
open MLHs

S.N.	MLH locations	PoDs covered
1	Achham	Accham
2	Bhojpur	Bhojpur
3	Dadheldhura	Baitadi
4	Gulmi	Gulmi
5	Ilam	Ilam
6	Khotang	Khotang
7	Mahottari	Dhanusa
8	Okhaldhunga	Okhaldhunga
9	Pyuthan	Pyuthan
10	Ramechhap	Ramechhap
11	Salyan	Rukum West
12	Tanahu	Lamjung

and a minimum of 1 POD can be served by an MLH. Figure 4 shows the spatial location of 12 MLHs and the PoDs served by MLHs over the map of Nepal.

To understand the results and the location selection process, we dissect the performance of the 59 candidate MLHs selected in this study. The 59 MLH candidates can further be categorized based on their performance over coverage distance and constraints satisfaction. Among the 59 candidate MLHs, 19 satisfy the coverage requirement, 20 the three constraint sets and only 12 satisfy both coverage requirements and all three constraint sets. As a result, the model selected 12 MLHs to cover 21 PoDs, leaving 11 PoDs uncovered.

4.2 Focus group discussion

4.2.1 Population sample selection. A population sample of 28 participants was chosen for the focus group discussion based on convenience sampling. The population sample represented a total of 22 different stakeholders who are active members/contributors to the humanitarian

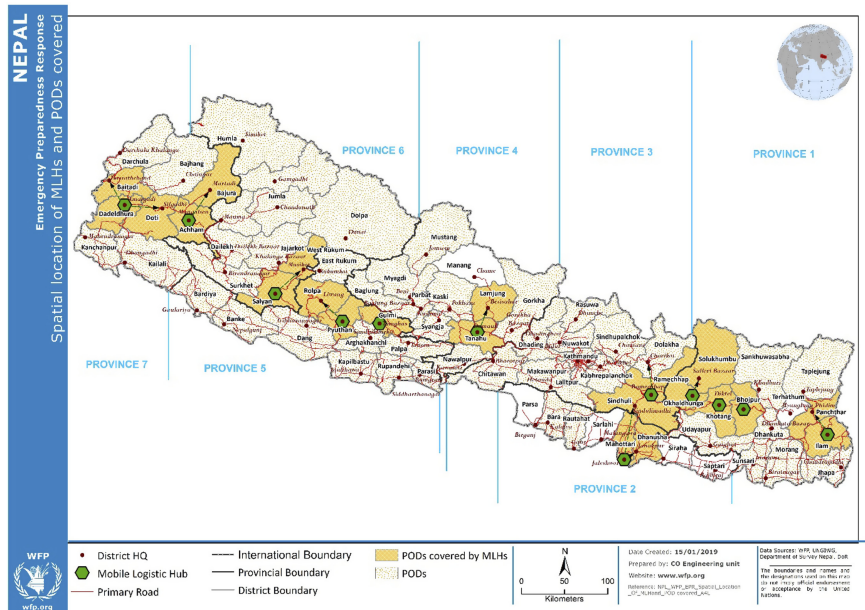


Figure 4.
Spatial location of
MLHs and PoDs
covered

sector in Nepal. The population sample includes humanitarian stakeholders, donors (active in emergency preparedness), UN agencies, members of the logistics cluster, government agencies, national and international non-governmental organizations, academic institutions and the security forces (military and police) of Nepal.

4.2.2 Group formation, structure and composition. To select MLHs to be placed in different parts of Nepal, participants were divided into three groups: Group I, Group II and Group III. During the group formation, participants were given a free choice to join any of the groups based on their personal preference, area of expertise and past working experience in any of the provinces/geographical region. Group I was assigned provinces 1 and 2, Group II was assigned provinces 3 and 4 and Group III was assigned provinces 5, 6 and 7. Group I comprised of 7 participants, Group II comprised of 9 participants and Group III comprised of 12 participants.

4.2.3 Outcomes of focus group discussions. Among the 12 MLHs selected by the optimization model, 4 MLHs are located in province 1, 1 MLH in province 2, 1 MLH in province 3, 1 MLH in province 4, 2 MLHs in province 5, 1 MLH in province 6 and 2 MLHs in province 7 as shown in Table 2. Among the 4 MLHs selected by the mathematical model for province 1, Okhaldhunga, Bhojpur and Khotang were selected as 2nd, 3rd and 4th priority by the focus group. The first priority was given to Terhathum, a new MLH location proposed by the group on the premise that it can cover Sankhuwasaha and north of Dhankuta which are uncovered. Also, MLH at Illam was recommended to move to Panchthar on the premise that Panchathar provides better coverage, has connections to highways and offers better security due to the presence of armed police forces.

In province 2, Mahottari, the MLH location proposed by the study, was decided as the best location, hence proceeded as the first priority. Also, in province 3, Ramechhap, the MLH location proposed by the study, was agreed unanimously by the group, hence proceeded as the first priority. In province 4, Tanahu, the MLH location proposed by the study, was suggested to be removed with the rationale that the FLB in Pokhara, which is the northeastern neighboring district, is more capable of covering Tanahu along with other neighboring districts within province 4. Instead of Tanahu, MLH location was proposed to be shifted to Gorkha due to its better accessibility and potential to cover neighboring Dhading in province 3 as the 2nd priority. Pyuthan and Gulmi, the MLH locations proposed by the study in province 4, were, respectively, proposed as the 4th and the 5th priority unanimously.

In province 6, Salyan, the MLH location proposed by the study, was not recommended by the group on the rationale that it can be covered by FLBs in Nepalgunj and Surkhet. Instead, MLH location was suggested to be shifted to West Rukum as the 3rd priority on the premise that a road from Jajarkot to Dolpa and East Rukum is planned for the near future. In the same province, a new MLH location in Kalikot was proposed as the first priority. The group estimated that MLH in Kalikot can potentially cover PoDs in Dailekh, Jumla, Mugu and part of Bajura. In province 7, among the 2 MLH locations proposed by the study, Achham was agreed unanimously by the group as the 2nd priority, and Dadeldhura was recommended to be shifted to Baitadi for wider and better coverage of PoDs with first order priority.

Finally, the focus group identified five locations as the first-order priority for the establishment of MLHs. The five MLHs are to be established in Khodpe in Baitadi district, Nagma in Kalikot district, Bardibas in Mahottari district, Ramechhap in Ramechhap district and Basantapur in Terhathum district. These locations have been approved by the Ministry of Home Affairs, under the Government of Nepal, for the establishment of MLHs in real life.

To understand the importance of incorporating focus group discussion, it is important to note that among the five MLH locations vetted by the Government of Nepal, Mahottari and Ramechhap are taken from the study results, whereas Baitadi, Kalikot and Terhathum were recommended by the participants of focus group discussion based on the results of the study. This highlights the fact that the results of the mathematical model alone are difficult to

Group	Province	Proposed MLH locations by study	Proposed MLH locations by focus group discussion		Remarks
			District	Exact location	
Group I	Province 1		Terhathum	Basantapur	1 st priority
		Okhaldhunga	Okhaldhunga	Manebhanjyang	2 nd priority
			Panchthar	Gopetar	3 rd priority
		Bhojpur	Bhojpur	Dingla	4 th priority
		Khotang	Khotang	Halesi	5 th priority
	Ilam				Not recommended
	Province 2	Mohattari (Jaleswor)	Mohattari	Bardibas	1 st priority
Group II	Province 3	Ramechhap	Ramechhap	DHQ	1 st priority
	Province 4	Tanahu			Not recommended
			Gorkha	Palungtar	2 nd priority
Group III	Province 5	Gulmi	Gulmi	DHQ	5 th priority
		Pyuthan	Pyuthan	DHQ	4 th Priority
	Province 6	Salyan			Not recommended
			West Rukum	Chaurjahari	3 rd priority
			Kalikot	Nagma	1 st priority
	Province 7	Achham	Achham	Sanfebagar	2 nd priority
		Dadeldhura			Not recommended
		Baitadi	Khodpe	1 st priority	

Note(s):

	8 MLH locations endorsed by group
	4 MLH locations not recommended by group
	6 New MLH locations proposed by group

Table 2.
Summary of the outcomes of focus group discussion

implement in real life. It is because quantitative data and measures alone cannot capture the true situation, especially in developing countries. The results of this study also illustrate the importance of involving experts and their knowledge specific to the country and the region for making strategic decisions that can be implemented in real life.

4.3 Practical implication and policy recommendation

Based on the results of the model, currently 11 PODs remain uncovered by selected MLHs. It is noteworthy that the 11 PoDs uncovered by the MLHs within the scope of this study are all located in remote areas of Nepal, which are difficult to access even during normal circumstances. Nonetheless, a portion of approximately 1.34 million population living in these districts are still vulnerable to the three major disasters. Therefore, we further explore how 11 uncovered PoDs can be encompassed within the emergency preparedness strategy.

Accommodating 11 PoDs could require relaxation of either or both of the constraints imposed in the mathematical model. Eleven uncovered PoDs also repeat themselves as the candidate MLHs; a closer observation at the performance of these candidate MLHs reveals

that all the 11 PoDs perform poorly, especially in terms of transportation accessibility. The MLH candidates at Bajhang and Kalikot perform poorly in terms of the level of development, and MLH candidate at Rukum East has composite disaster vulnerability close to the maximum value. As such, we performed a sensitivity analysis to identify the sensitivity of the mathematical model to the coverage distance. Upon increasing the coverage distance to 150 km, PoDs located in Sankhuwasabha can be covered by MLH candidates located in either Dhankuta or Terhathum, where Dhankuta corresponds to a lower internode distance. On the other hand, other PoDs remain uncovered. Increasing the coverage distance to 200 km did not contribute to additional coverage. Further increase of coverage distance to 300 km resulted in coverage of additional PoDs located in Jajarkot, Jumla and Kalikot by MLH candidate in Dailekh and PoDs in Mustang by MLH candidates in Nawalpur and Syangja.

As a short-term solution to improve coverage to these districts, concerned authorities may consider: (1) establishing additional MLHs in these districts by relaxing the three constraints while putting efforts to improve the accessibility to and from these districts in general, and (2) increasing the coverage distance. It is important to note that both the improvement measures have associated weaknesses, for example, establishing an MLH in a location with poor accessibility may lead to difficulty in movement, handling, and distribution of emergency relief materials in case of a disaster occurring and stagnation of the established MLH due to operational unsustainability and so forth, whereas an increase in coverage distance will lead to decreased service level. Long-term and more sustainable approach to cover 11 PoDs should focus on (1) improving the road access and connectivity to other districts for solving accessibility issue, (2) improving education, health quality and creating employment opportunities which will ultimately upgrade human development index and (3) deploy disaster prevention and mitigation strategies to reduce CDVI.

5. Conclusion

In this study, we determined the optimal number and location of MLHs by utilizing the modified version of MCLP as an integer task considering three sudden-onset disasters and three constraints that capture the status of transportation accessibility, human development and disaster vulnerability of 77 districts of Nepal. The three sudden-onset disasters – earthquake, landslide and flood – which combined have the highest frequency of occurrence among all types of natural disasters in Nepal; also, these natural hazards often claim a large number of lives and also damage infrastructure. The model identified 12 MLHs to be established in Achham, Bhojpur, Dadelhdhura, Gulmi, Illam, Khotang, Mahottari, Okhaldhunga, Pyuthan, Ramechhap, Salyan and Tanahu districts for prepositioning MSUs. The 12 selected MLHs cover 21 PoDs within a coverage distance of 100 km.

We conducted a national-level focus group discussion involving key humanitarian stakeholders, donors (active in emergency preparedness), UN agencies, members of the logistics cluster, government agencies, national and international non-governmental organizations, academic institutions and the three wings of the security forces (army, police and armed police) in Nepal to identify the five MLHs to undergo immediate establishment in Nepal. The focus group selected Baitadi, Kalikot, Mahottari, Ramechhap and Terhathum as the five first priority locations for MLH establishment. These five locations have been approved by the Ministry of Home Affairs under the Government of Nepal to undergo implementation. The focus group discussion also enabled us to pinpoint the location of MLHs to city-level granularity, which was otherwise impossible with data available on hand. By amalgamating scientific research with expert knowledge, we were able to obtain findings acceptable to a wide range of stakeholders in Nepal.

Our study has some limitations that should be addressed in future works. Although multiple experts' judgments were obtained via focus group discussion, subjectivity and possible bias are inevitable. Distances are calculated between each district headquarters, and

these headquarters are assumed to have proper road access to and from the demand nodes. The study does not consider demand coverage provided by warehouses owned by entities other than the Government of Nepal, the World Food Programme and Nepal Red Cross Society in Nepal merely due to the lack of data. Overall, the quantitative results of the study are purely based on the data available during the study period; therefore, having updated data could improve the quality of the results.

Further extension of this study can also focus on how sourcing can be linked to the established MLHs by realization of multiple-disaster scenarios in terms of demand, transport accessibility and travel time. Future work can also focus on how to incorporate anticipated demand and associated demand variations during actual disaster response. With slight modifications, this model can be replicated for other vulnerable countries. Its applicability is not limited to humanitarian supply chain design; with some adjustments and improvisation, the model can be used to determine locations for search-and-rescue centers, emergency medical centers and so forth. With adjustment, the same technique can be applied to determine locations for facilities for both military and civilian purposes (including public facilities like fire stations or health centers). In conclusion, we hope that researchers will be able to use our findings to enhance disaster response in vulnerable countries around the world.

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